26.3: A Novel Method for the Formation of Polymer Walls in Liquid Crystal/Polymer Displays

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Abstract

We have investigated the formation of polymer walls using a patterned electric field for rugged liquid crystal (LC) displays. The patterned electric field induces patterned phase separation. The LC molecules segregate in the high electric field regions, i.e. pixels, whereas the monomers segregate in the low field regions, i.e. inter-pixels. Subsequent photo-polymerization forms polymer walls between the pixels. We discuss the features of polymer walls formed by using this novel method.

Introduction

Cholesteric liquid crystal materials have been of great interest for reflective display applications. These materials have been utilized to prepare displays that have two stable states at zero field: a selectively reflective planar state and a weakly scattering focal conic state [1-3]. The first bistable, polymer stabilized cholesteric texture (PSCT) devices involved a low concentration of photo-curable monomers dispersed in the cholesteric liquid crystal mixture.

Relatively high polymer content formulations have also been used to produce bistable reflective PSCT displays [4-6]. These formulations have some potential advantages over the low, or no, polymer content formulations since polymer networks greatly increase the mechanical stability of displays. The network adheres the top and bottom substrates, and provides a self-sustaining polymer structure making possible flexible devices of large area with relatively uniform thickness. The Liquid Crystal Institute has successfully demonstrated a four-inch-square bistable reflective PSCT display with 320 by 320 pixels [6] and a writing tablet, fabricated from high polymer content formulations using plastic substrates. However, the high polymer content formulations produce dense polymer networks that result in significant light scattering in the focal conic state. Light scattering reduces the color purity and brightness of reflected light in the planar state, and consequently, the contrast of a display.

In order to improve the brightness and contrast while maintaining the structural benefits of polymer networks, polymer walls have been formed in high polymer content PSCT displays [7]. The formulations were composed of ultraviolet (UV) curable monomers and chiral nematic liquid crystals. The formation of polymer walls was carried out by irradiating selective area of a cell with UV light through a patterned photo-mask. This technique utilizes phase separation induced by photo-polymerization [8]. This method was also used by researchers from Sharp in the formation of polymer walls for the fabrication of axially symmetric aligned microcells (ASM) [9] and polymer matrix super-twisted nematic liquid crystal displays (PM-STN-LCDs) [10]. The polymer walls in the inter-pixel regions not only improve the electro-optic characteristics of PSCT displays, but also provide

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excellent pressure resistance preventing distortion of a display image [7,10].

In this paper we present a novel method for the formation of polymer walls in high polymer content formulations, using patterned electric field-induced phase separation. This new method does not require a photo-mask. Utilizing the electrodes used to address a display provides a simple lower cost process for the fabrication of a rugged LC display.

Patterned-Field-Induced Wall Formation

The patterned electric field is produced using a cell with a cross pattern of indium tin oxide (ITO) electrode lines. The cell gap was controlled using 4.5 μm plastic sphere spacers. The formulation we have studied was a mixture of a chiral nematic mixture (CNM) and photo-polymerizable monomers such as Norland optical adhesive 65 (NOA65). The cell was filled with this homogeneous, isotropic formulation, and the electric field was then applied using the electrode lines of the substrates.

Since the CNM has a larger dielectric constant than the monomers, it experiences a greater force from the fringing fields around the inter-pixel regions subject to Kelvin type force of the form [11]:

$$F = P \cdot \nabla E \quad \text{------------------ (Eq. 1)}$$

where P is the polarizability of the material and E is the field strength. The CNM molecules, therefore, are forced to segregate in the high-field regions, i.e. pixels, and the monomers segregate in the low-field regions, i.e. inter-pixels. Subsequent blanket UV-irradiation forms polymer walls in inter-pixel regions as a result of patterned phase separation.

The effect of a patterned electric field on the phase separation temperature of a CNM/NOA65 mixture formulation during cooling has been investigated as a function of the NOA65 concentration (10 – 30% w/w) [12]. The results show that the phase separation temperature during cooling increases with the patterned field in the experimental range of field strength up to 17.8 V/μm. The optimum concentration of monomers for polymer wall structure was found to be close to the volume proportion of the inter-pixel regions of the cell.

In order to find the optimum formation temperature, the polymer walls have been formed at different temperatures using plastic substrates with resolution of 100 dpi. The formulation contained 15% (w/w) of NOA65 and 85% (w/w) of a BL061/E44 (76/24) mixture as CNM. Cells were capillary-filled with the homogeneous, isotropic mixture at 100°C, and kept for 5 minutes before an electric field (AC, 60 Hz) of 17.8 V/μm was applied. With the field applied, the cell was cooled at 1°C/min and maintained at a lower temperature and kept for 70 minutes from the start of cooling. The cell was then UV-irradiated for 20 minutes to cure the NOA65 monomers using an Electro-Lite ELC 4000 unit of 25 mW/cm^2 intensity at 365 nm wavelength.

Figure 1(a) shows polymer walls obtained by cooling to 60°C. The walls are a "honeycomb" type with rough boundaries in the inter-pixel regions. Figure 1(b), however, shows that solid, well-defined walls with sharp and smooth boundaries can be obtained by cooling to 30°C. This result indicates that, during cooling with the field, two competing factors of molecular diffusion and material viscosity play significant roles on the patterned phase separation. As a result, the optimum temperature profile for patterned field-induced phase separation and, consequently, polymer wall formation starts at a high temperature with favorable high diffusion and ends at a low temperature

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where the high viscosity maintains the patterned separation.

electrode line pattern strongly affects the patterned separation.

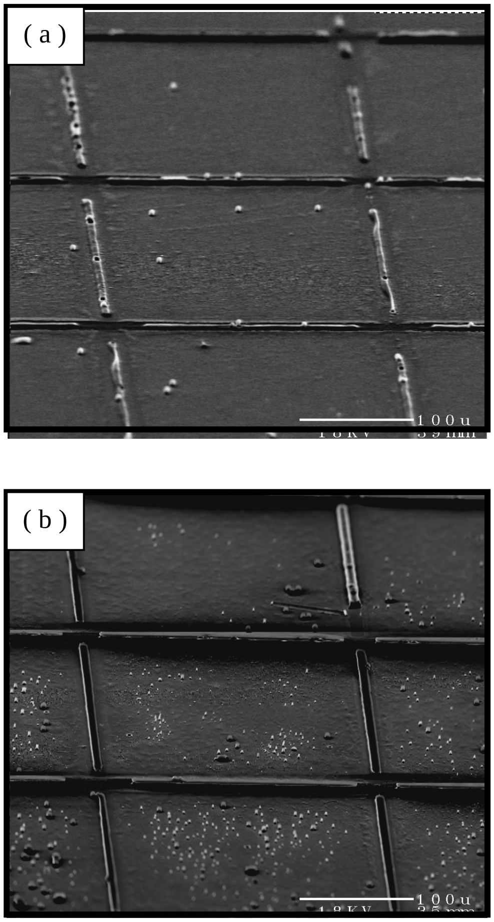

Figure 1. SEM micrographs of polymer walls obtained from a CNM/NOA65 (85/15) mixture formulation using plastic cells of 100 dpi: The cell was cooled from 100°C with 17.8 V/μm at a rate of 1°C/min to (a) 60°C and kept for 30 minutes, or (b) 30°C, and then UV-cured for 20 minutes.

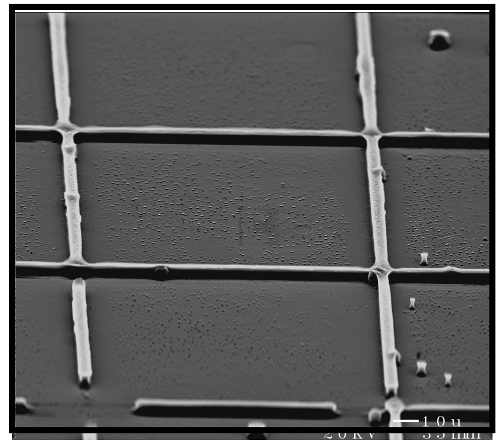

Figure 2. SEM micrograph of polymer walls obtained from a CNM/NOA65 (90/10) mixture formulation using glass substrates of 200 dpi with an electric field of 17.8 V/μm.

Using glass substrates with a resolution of 200 dpi, the patterned phase separation was also induced from a mixture formulation containing 10% (w/w) NOA65. The cell was prepared in a similar way but cooled to room temperature, and UV-irradiated to form the polymer walls. As shown in Figure 2, the polymer walls have very well-defined structure with sharp boundaries. This result indicates that the dimensions of

Reflectivity Improvement with Polymer Walls

Reflectivities of the cells derived from CNM/NOA65 mixture formulations using glass substrates of 80 dpi have been compared in their green planar states, as shown in Figure 3. The cell using temperature-induced phase separation followed by UV-curing, i.e. without polymer walls, shows a maximum reflectivity of 35%. However, the cell with polymer walls exhibits a maximum reflectivity of approximately 50% even though both cells were obtained from the same formulation of 10% (w/w) NOA65. The large increase is due to the decrease in light scattering from the polymer networks in the pixels. The polymer is mostly in walls in the inter-pixel regions. Increasing the concentration of NOA65 reduces the maximum reflectivity due to the increase in light scattering resulting from the expansion of polymer network domains in both pixel and inter-pixel regions [12].

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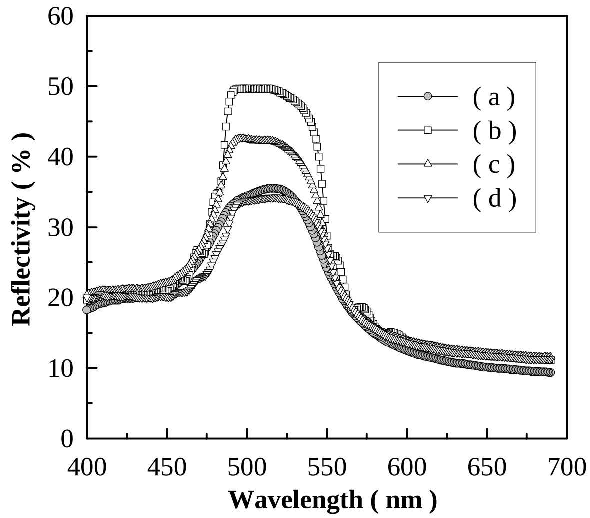

Figure 3. Reflectivities of the cells (80 dpi) made from CNM/NOA65 mixtures in planar state: (a) 90/10 without walls, (b) 90/10 with walls, (c) 80/20 with walls, and (d) 70/30 with walls.

Conclusion

We have introduced a new method for the formation of polymer walls for high polymer content LC displays. The application of a patterned electric field using electrodes for addressing a display induced the patterned phase separation. Upon UV-irradiation, without using a photo-mask, polymer walls have been formed in the inter-pixel regions. In order to understand and optimize this process we have discussed the factors controlling wall formation such as the composition of the formulation, the pattern of the electric field, the field strength, and temperature. This technique can be used with other LC devices such as TN and STN displays.

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